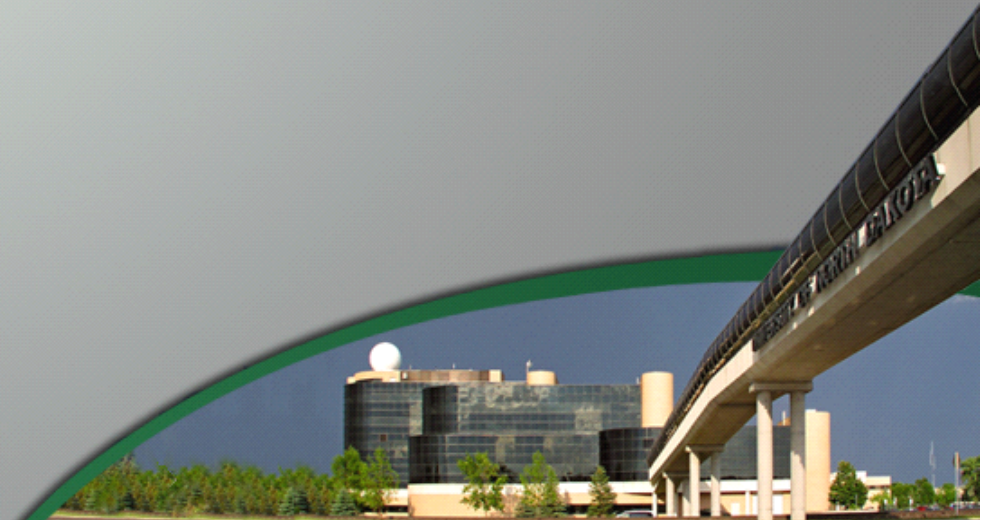


Comparison of Cloud Properties in Ice-Phase Layer of Deep Convective Systems between GOES, CERES-MODIS and ARM Retrievals

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Motivation

- CERES ST has not yet evaluated their retrieved ice cloud microphysical properties of DCS due to lack of reliable radar observations and retrievals.
- If radar signals are not significantly attenuated during a DCS, the radar determined cloud-top height (CTH) can be used to validate the satellite retrieved CTH of DCS.
- However, it is a challenge to retrieve the ice cloud microphysical properties of DCS using the ARM radar data due to **the attenuation of cloud radar reflectivity** by heavy precipitation, **unknown particle size distributions (PSDs)** and **the habit of the ice particles in sampling volume**.
- Fortunately, the attenuated KAZR reflectivity measurements during the MC3E have been adjusted by a collocated unattenuated 915-MHz UAZR and disdrometer. The aircraft in-situ measurements (Wang et al. 2014) provide the best-estimate *IWC* and PSDs for validating the radar retrievals.



Goals

- 1) Validating the GOES and MODIS retrieved cloud-top height (CTH) using DOE ARM cloud radar derived CTH during the MC3E IOP (April-June, 2011).**
- 2) Validating the GOES and MODIS retrieved ice cloud microphysical properties (Upper layer) of DCSs using the newly developed retrieval method based on ARM adjusted KAZR reflectivity and aircraft in-situ measurements during the MC3E.**



ARM observations/retrievals during MC3E

1) Cloud-top height (CTH): KAZR (35 GHZ cloud radar) at DOE ARM SGP site

2) Particle Size D_e : using newly developed retrieval algorithm (Tian et al. 2014)

- Retrieving ice cloud particle size based on adjusted KAZR reflectivity**
- Our retrievals have been validated by UND aircraft in situ measurements.**

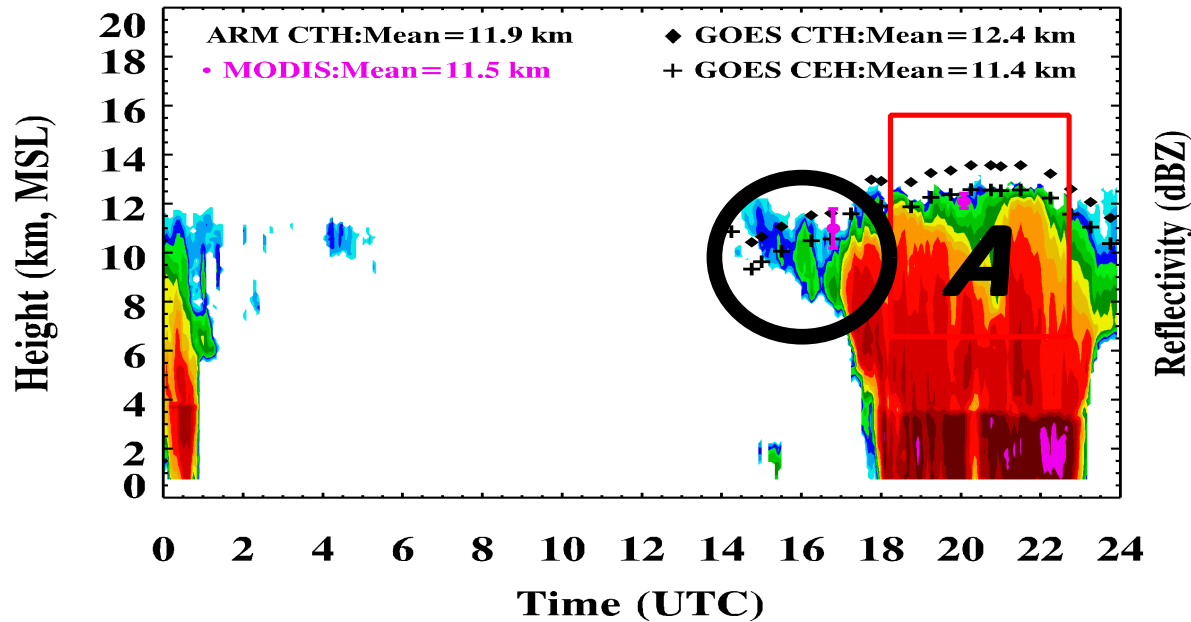


Objective 1

Cloud-top height (CTH) comparison between the ground-based radar (KAZR) and satellite (GOES/MODIS) retrievals (05/11; 05/20; 05/23; 05/24, 2011 during the MC3E)



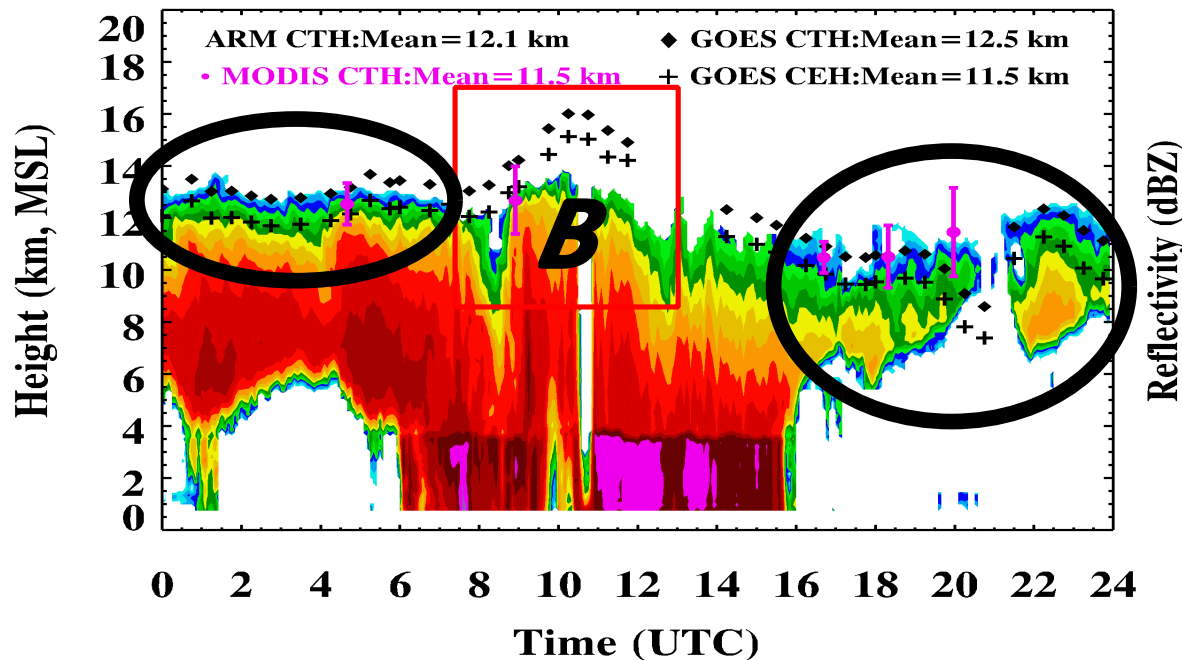
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On Average, **MODIS CTHs** agree very well with ARM CTHs, while GOES CTHs are 500 m higher and CEHs are 500 m lower than ARM CTHs.

Over Anvil regions, GOES derived CTHs agree well with ARM CTHs.

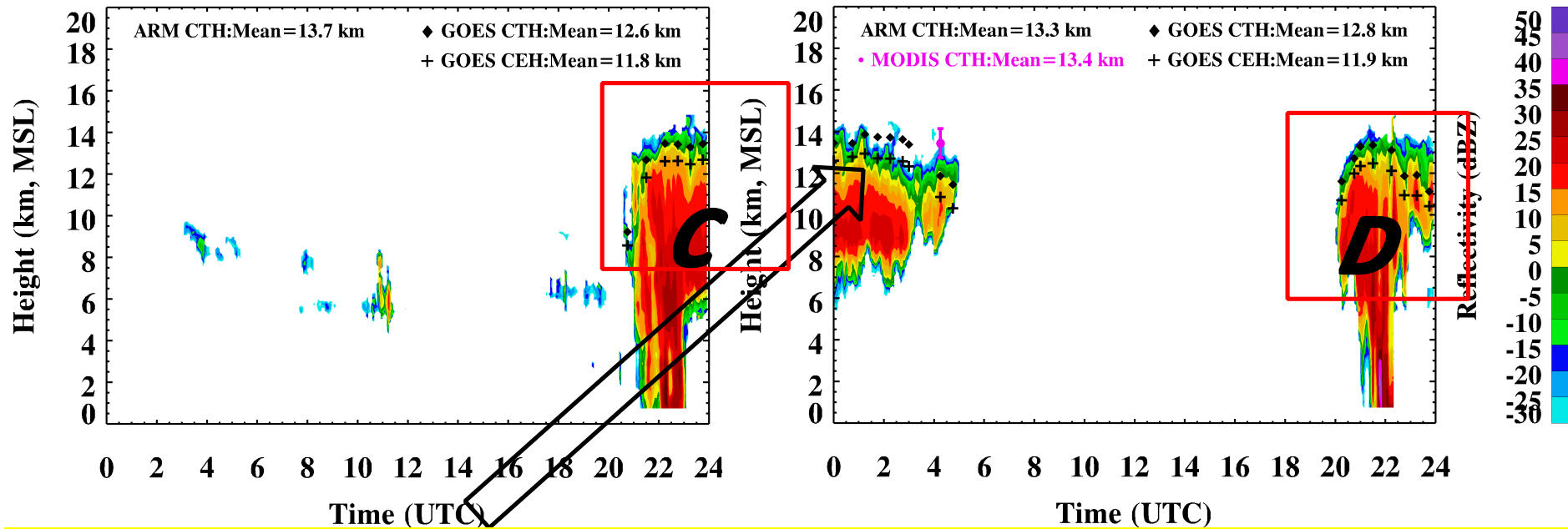
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Near convective cores (**A and B regions**), however, GOES derived CTHs are 1-2 km higher than radar CTHs because radar signals might be attenuated by the heavy precipitation.

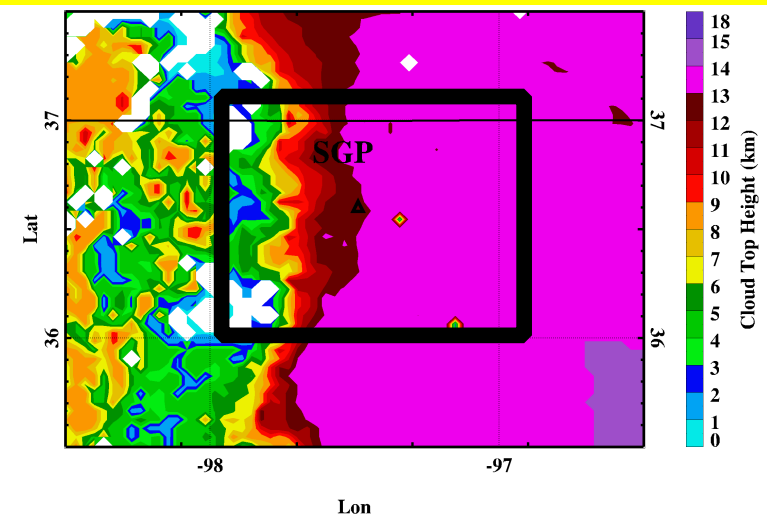
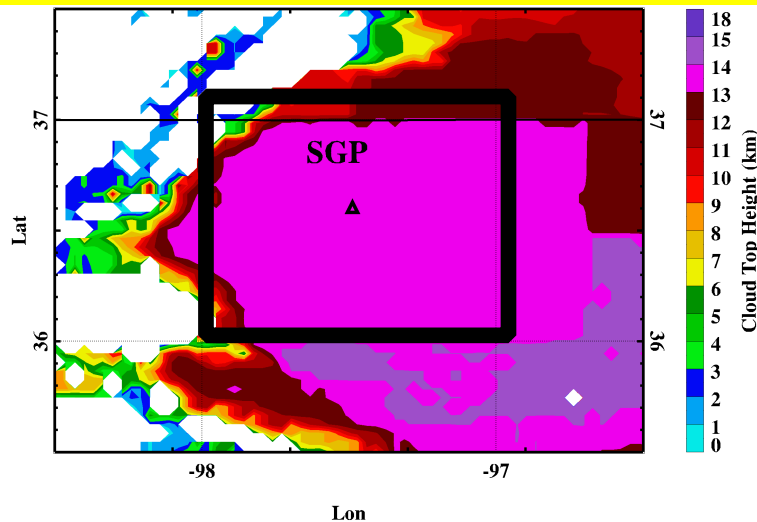
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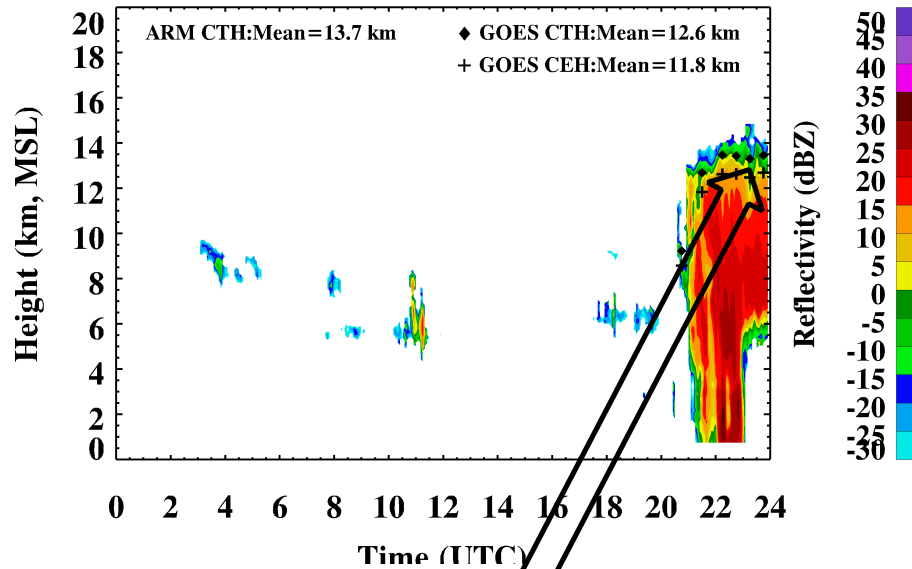
Again over Anvil regions, both GOES and MODIS derived CTHs agree well with ARM radar results.

Over **C and **D** regions, however, GOES derived CTHs are slightly lower than the radar CTHs because the GOES 1°X1° averages includes some lower clouds.**



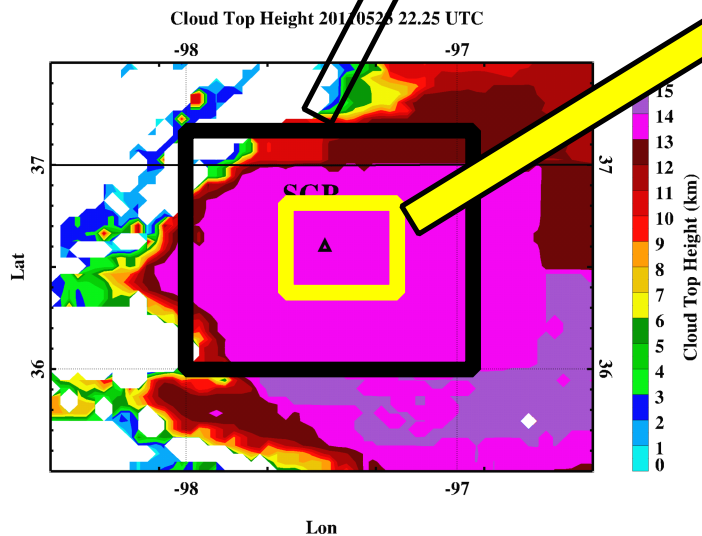
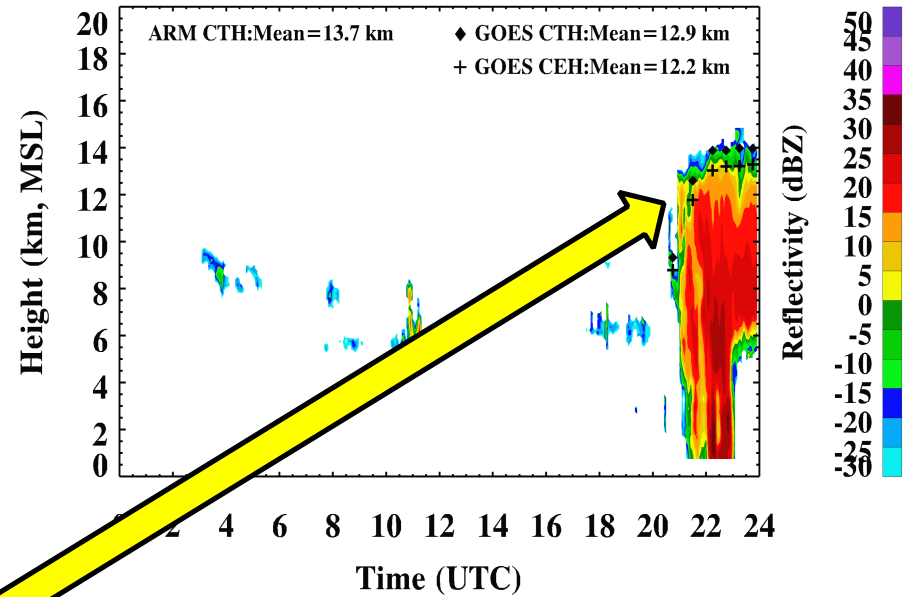
1°X1°

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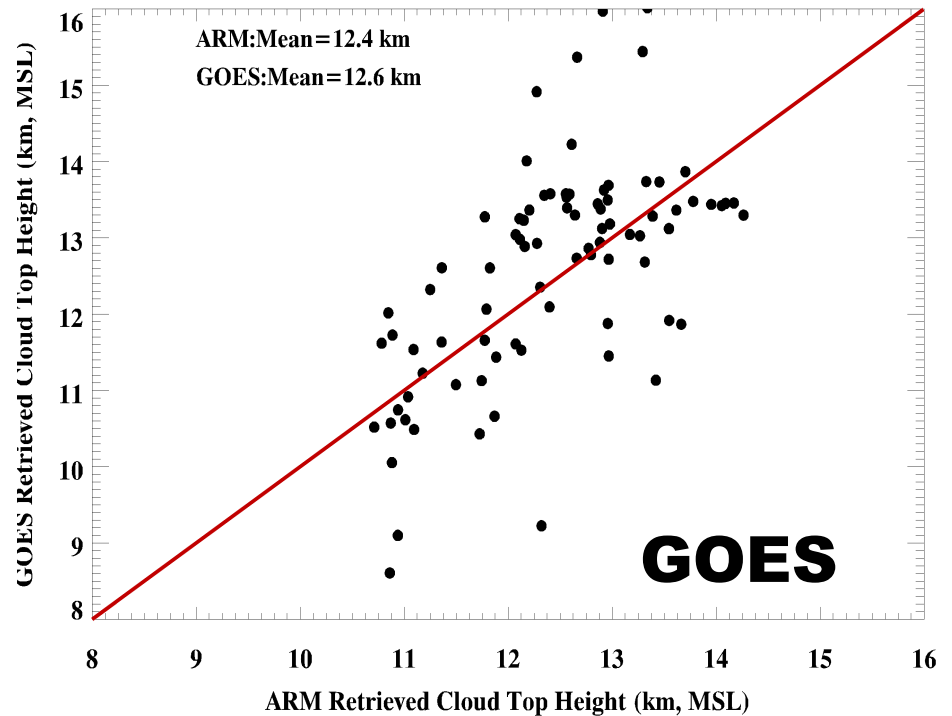
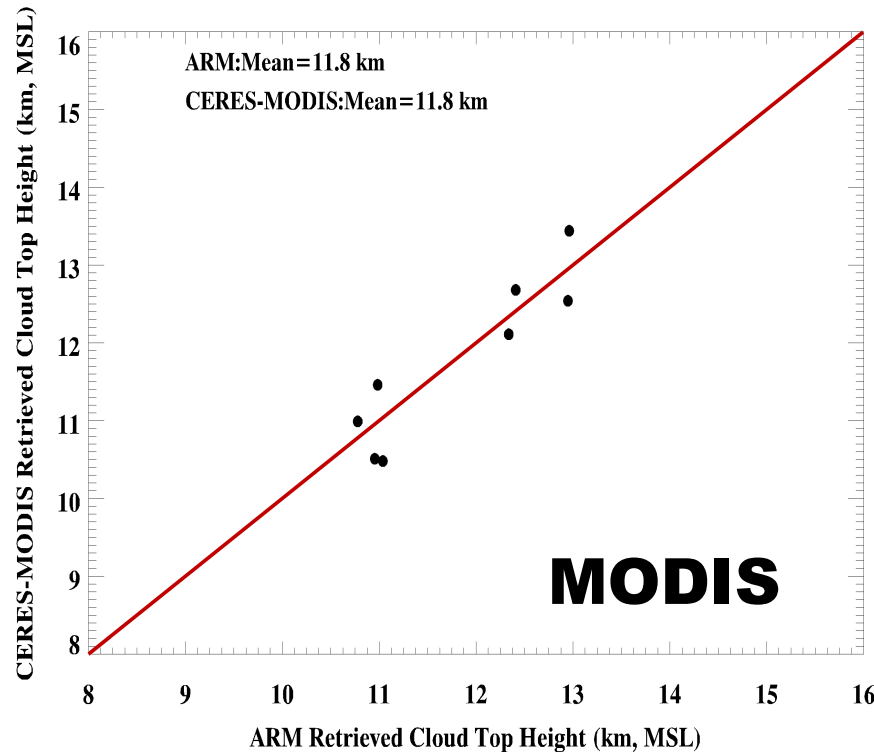
0.25°X0.25°

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GOES derived CTHs become higher, from 1°X1° average to 0.25° X 0.25° average. They agree better with ARM CTHs.

CTH Comparisons between GOES, MODIS and Radar



Conclusion I:

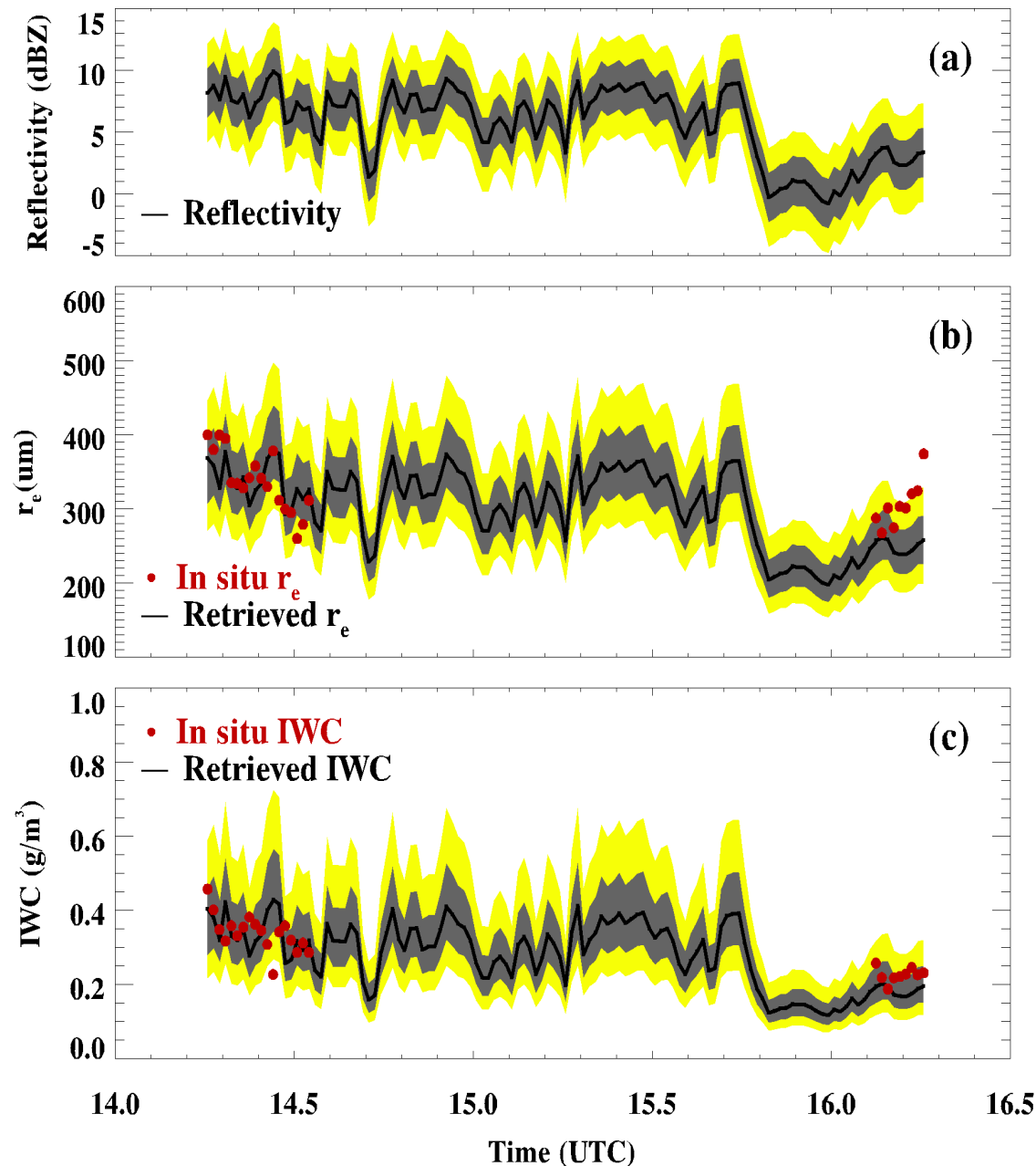
- 1) **CERES-MODIS retrieved CTHs have an excellent agreement with ARM radar CTHs although there are 8 overpasses.**
- 2) **GOES retrieved CTHs scatter around the ARM CTHs with nearly the same average. Some large differences are due to:**
 - a) **KAZR derived CTHs are lower due to attenuation of radar signals.**
 - b) **GOES1°X1°averages include some lower clouds**

Objective 2

Cloud Particle Size (D_e) comparison between ARM radar (KAZR) and GOES /MODIS retrievals during the MC3E (May 11th, 20th, 23rd, and 24th)



A newly developed method for retrieving ice cloud microphysical properties of DCS



→ Tian et al. (2014) developed a new method to retrieve the ice cloud *IWC* and r_e of DCS from adjusted KAZR reflectivity assuming a modified gamma distribution, size shape $a=2$, and a bullet rosette σ - D relationship.

2 dBZ uncertainty (gray shade) for the adjusted KAZR reflectivity leads to the uncertainties of 13% in r_e and 26% in *IWC*.

As demonstrated in Figure, the radar retrieved *IWC* and r_e have very good agreement with aircraft in-situ measurements.

Which kind of ice crystal habit should be used in ARM retrieval

To be consistent with the VISST cloud retrieval algorithms, the equation used to compute D_e is

$$D_e = \frac{\int D \cdot D \cdot L \cdot n(L) dL}{\int D \cdot L \cdot n(L) dL}$$

Where L is length and D is width of ice particle.

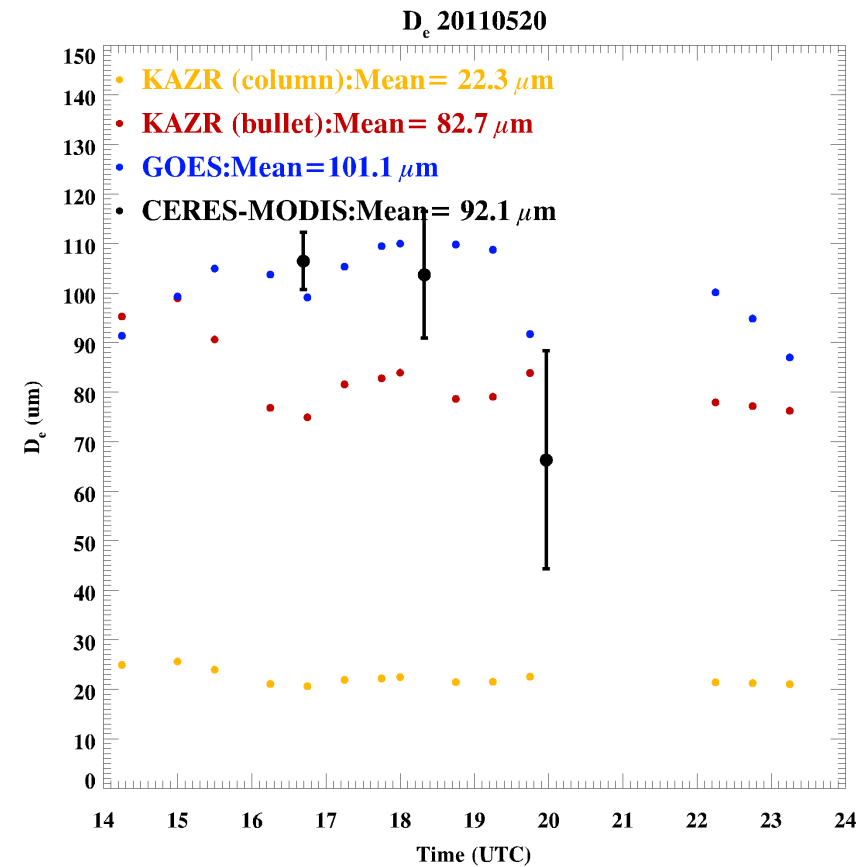
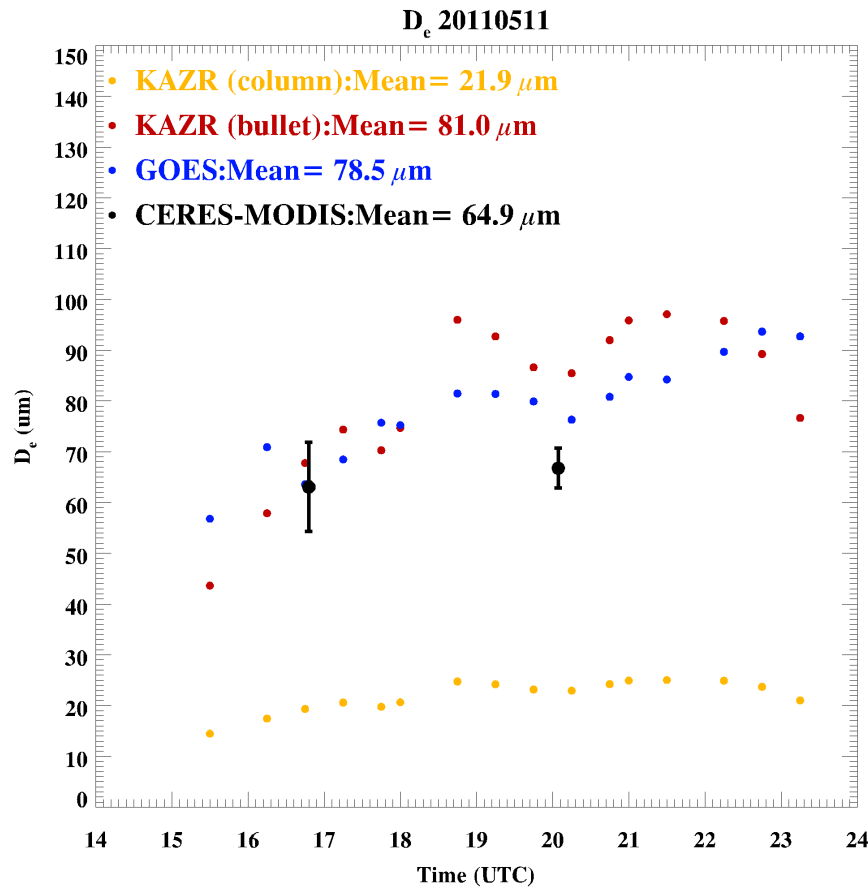
HEXAGONAL COLUMNS:

Wyser and Yang [1998] determined a functional relationship between L and D for the case of hexagonal columns given by

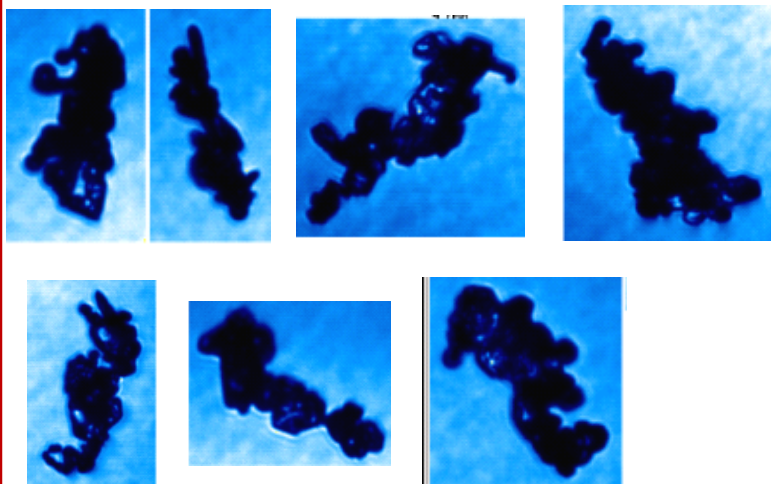
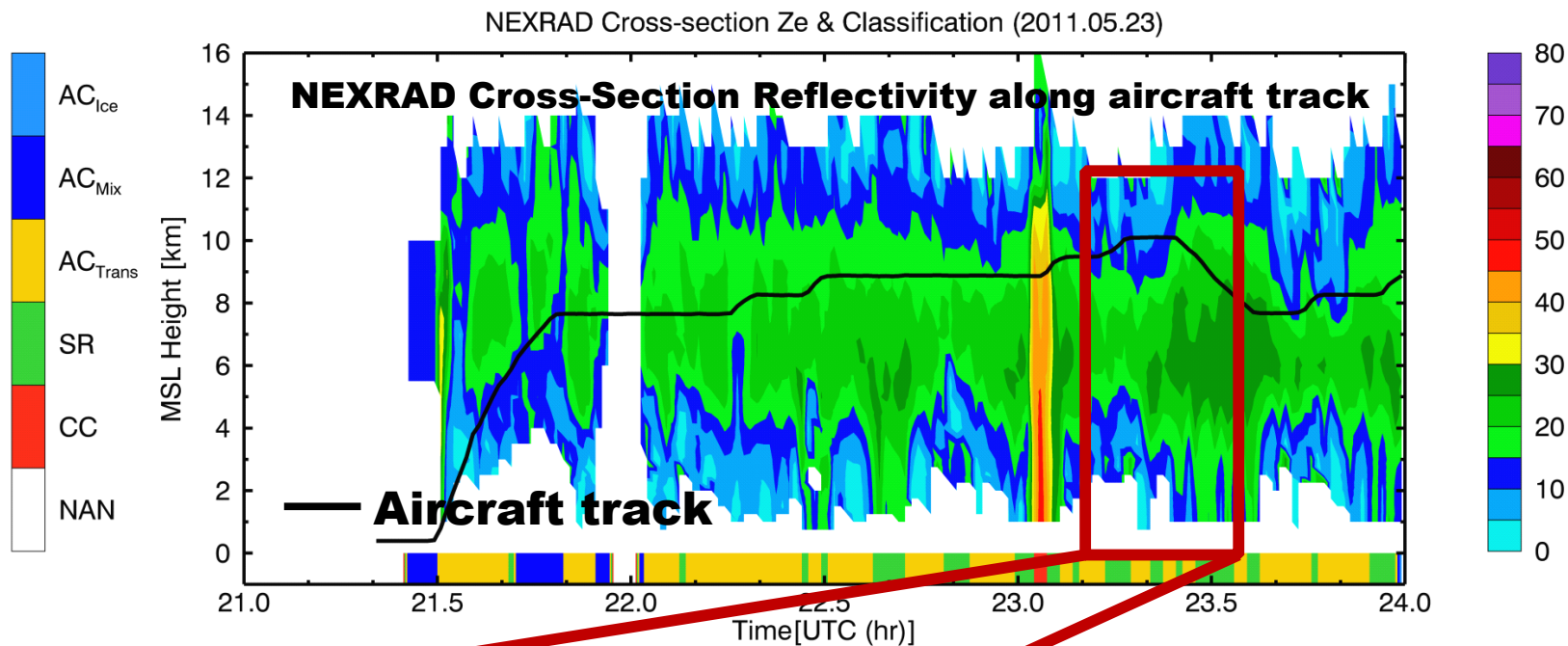
$$D = 2.5 L^{0.6}.$$

BULLET ROSETTE:

The aspect ratio (width/length: D/L) of bullets rosettes was found to be 0.4 (D=0.4L) on average in synoptically generated cirrus clouds in 2016 single rosettes and 971 aggregates of rosettes from in-situ aircraft CPI [Heymsfield et al., 2003].



- 1) **KAZR retrieved *De* values with hexagonal column habit are much lower than GOES/MODIS retrievals, while those with bullet rosette habits are very close to the GOES/MODIS retrievals for these two cases during the MC3E.**
- 2) **Therefore, we conclude that the bullet rosette habits (partially proved by aircraft CPI measurements on May 23) should be used for ARM retrieving the ice cloud microphysical properties of DCS.**



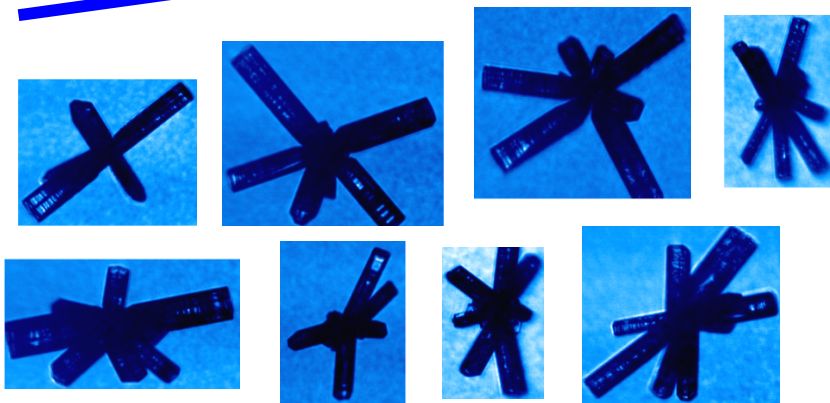
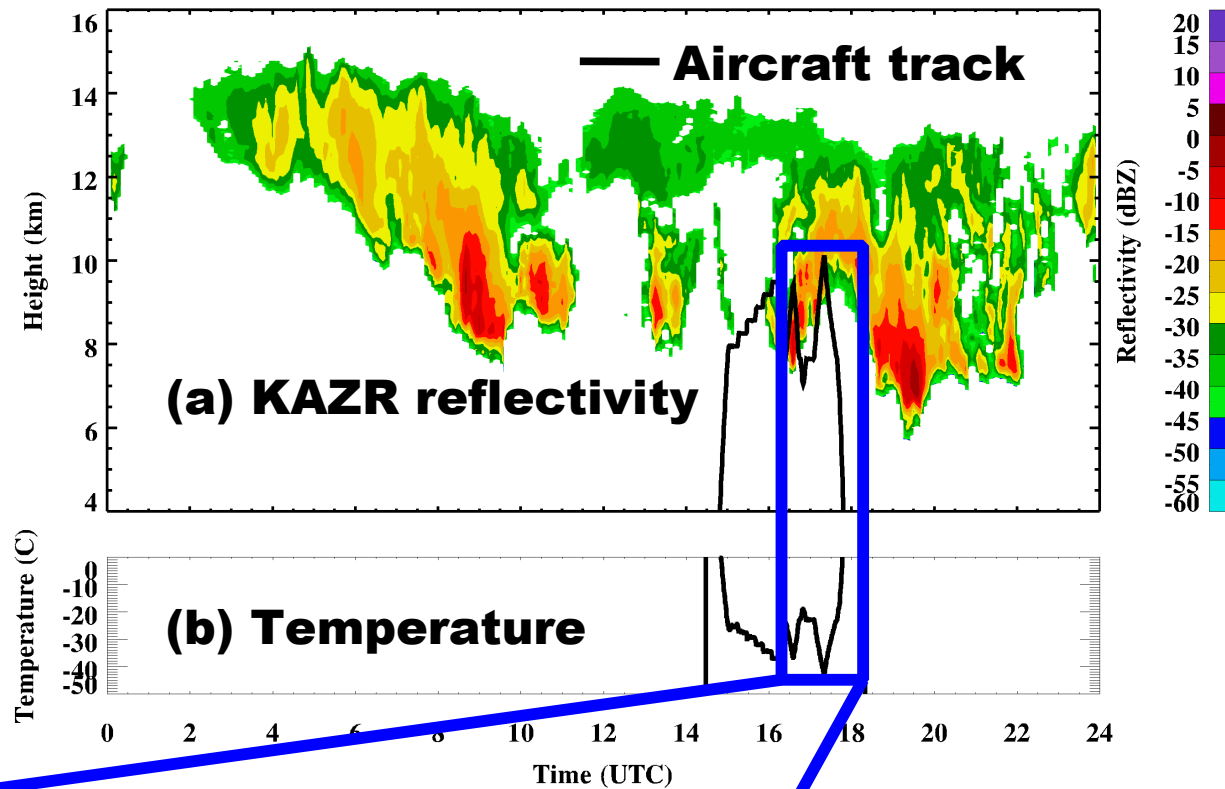
CPI images on 05/23 and 05/24 DCS cases

Almost all the ice particle habits imaged by CPI are aggregates in DCS cases.

For 35 GHz cloud radar, the bullet rosettes and aggregates have most similar backscatter information.

Thus, it is reasonable to assume bullet rosette habit for ARM retrieving the ice cloud microphysical properties of DCS.

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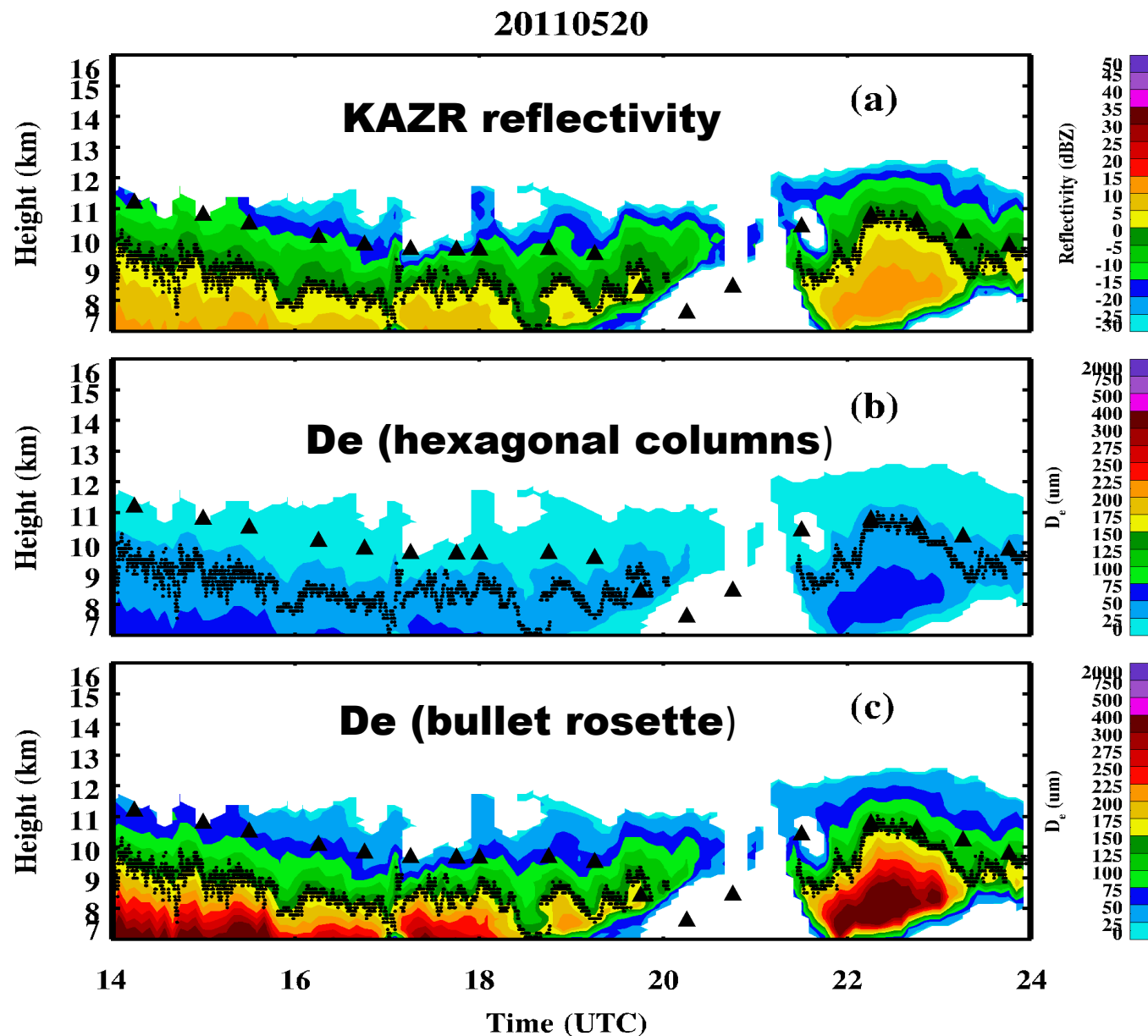


CPI images on June 2nd,
single layer cirrus cloud case

Almost all the ice particle habits imaged by CPI are bullet rosettes in June 2nd, a single layer cirrus cloud case.

Thus, even for the single layer cirrus cloud, the bullet rosette habits should be used for ARM retrieving the ice cloud microphysical properties.

If both ARM and satellite retrievals are correct, how can we average both ARM and satellite retrievals to make an apple-to-apple comparison?

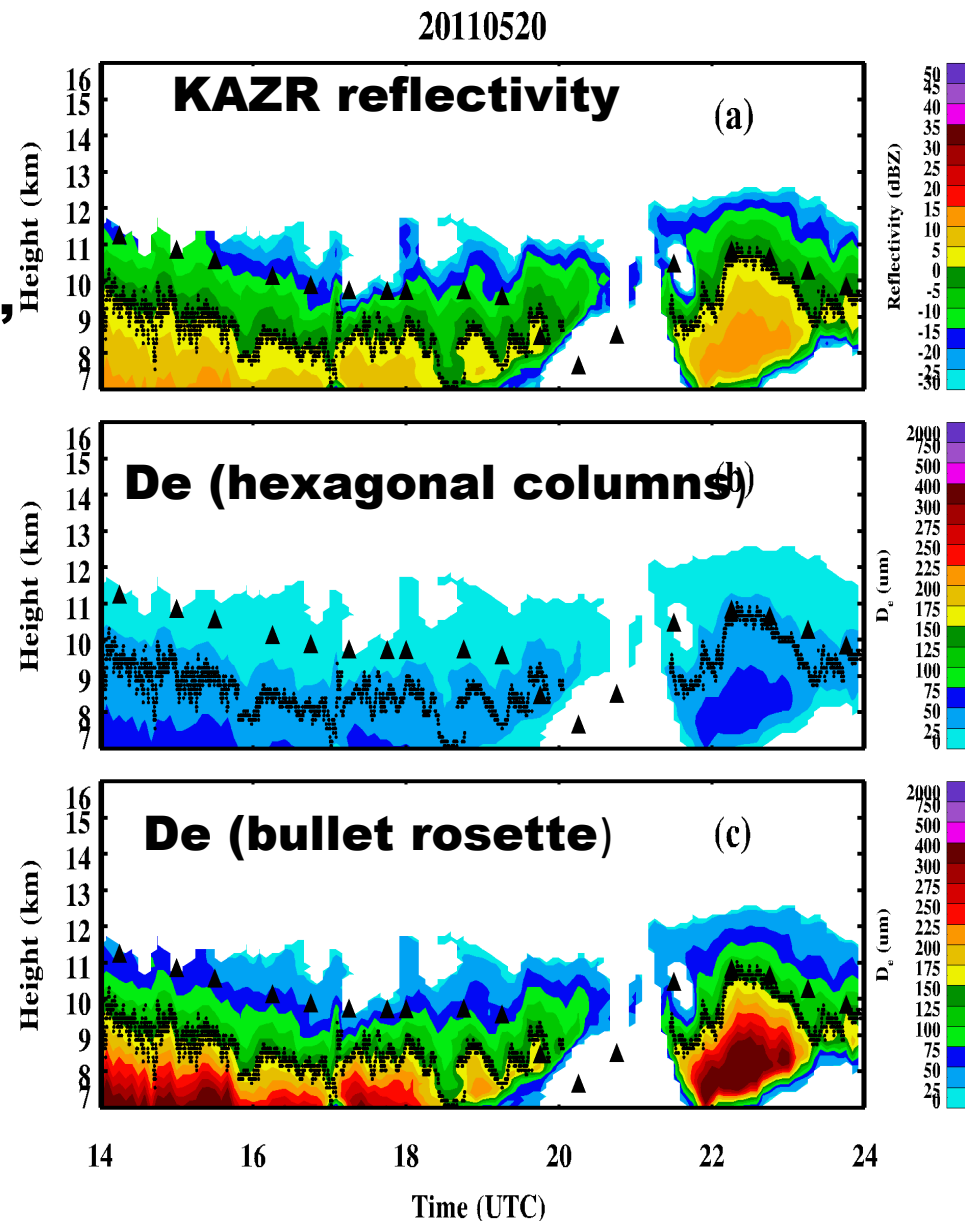


Following the spatial and temporal averaging method in Dong et al. (2002, 2008), the satellite retrievals are averaged within a $1^\circ \times 1^\circ$ grid box centered over the ARM SGP site, while the ARM retrievals are averaged within an hour (± 0.5 hr satellite overpass)

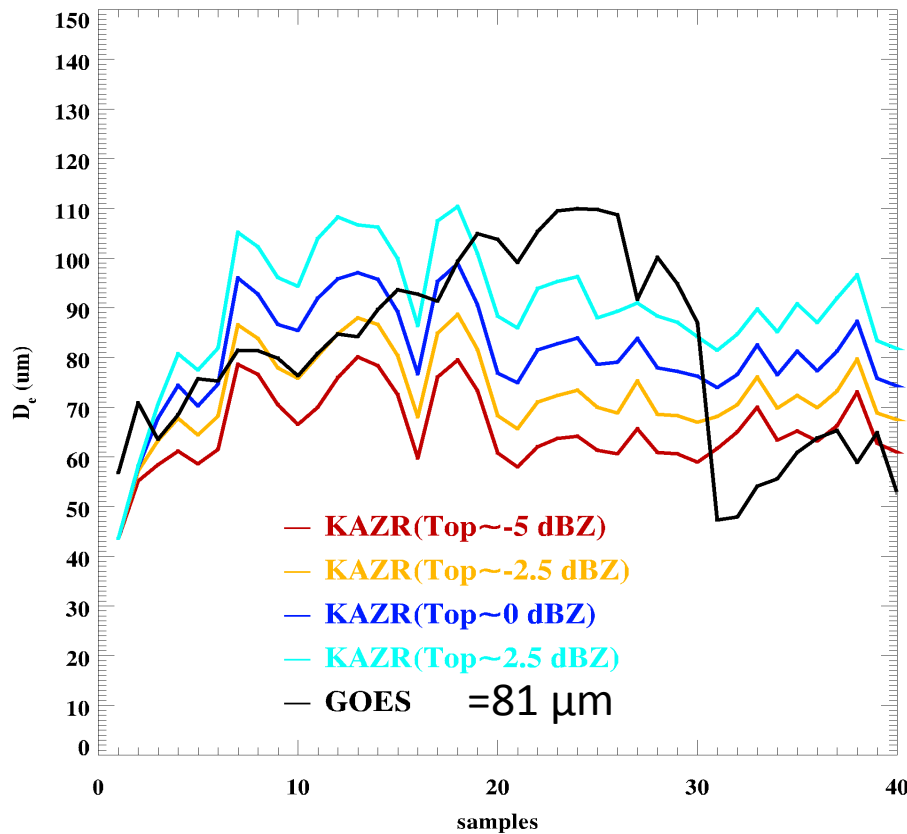
Next we should determine how to average the ARM retrievals vertically, or at which altitude the satellite retrieved D_e values represent for?

If both ARM and satellite retrievals are correct, how can we average both ARM and satellite retrievals to make an apple-to-apple comparison?

- According to *Minnis et al.* (2008), the satellite retrieved CEH (and D_e) should represent an optical depth of ~ 1.1 down from the cloud top, which corresponds to 1-2 km in ice clouds, even in optically thick ice clouds.
- Following this method, we set up the KAZR reflectivity threshold at 0 dBZ (black lines), then average the ARM radar retrieved D_e values from cloud top (-30 dBZ) to the altitudes at 0 dBZ to calculate the layer mean D_e values, and finally these layer-mean D_e values compare with MODIS and GOES retrievals.



A sensitivity to different reflectivity thresholds



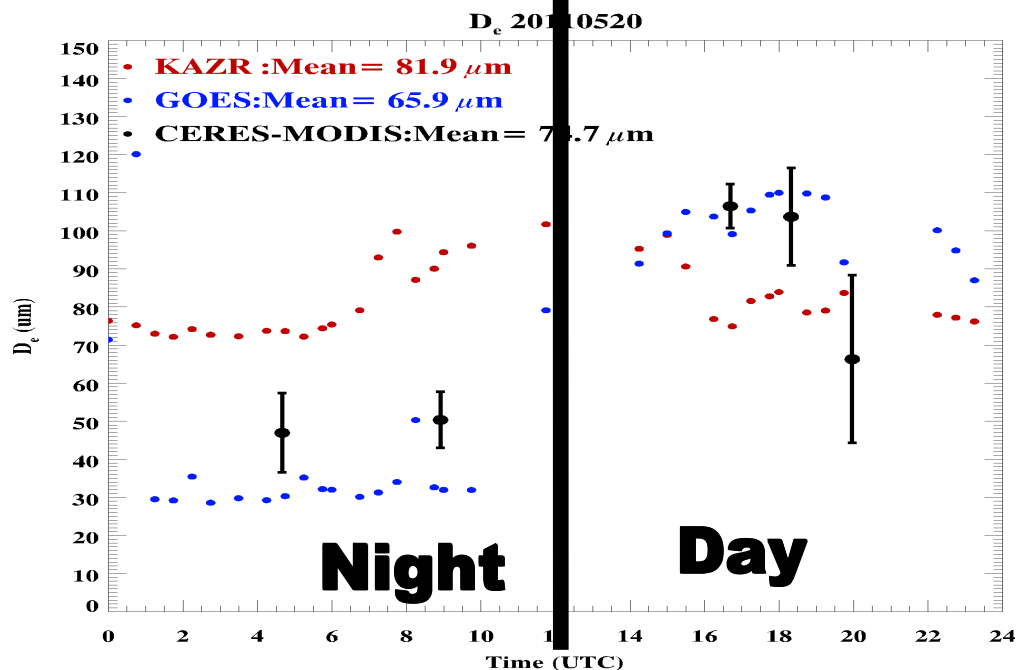
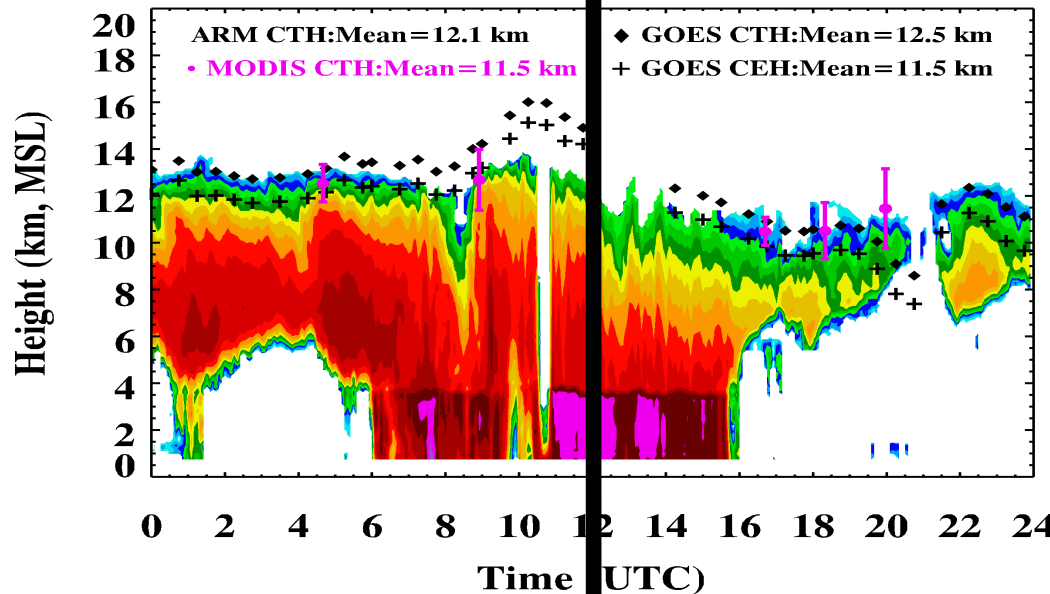
	-5 dBZ	-2.5 dBZ	0 dBZ	2.5 dBZ
KAZR retrieved Mean D_e	65.6	72.9	81	90
Mean($D_{e_{KAZR}}$)- Mean($D_{e_{GOES}}$)	-15.4	-8.1	0	9
Total Difference	9	7.8	8.4	10
RMSE	24.6	20.3	18	20
Correlate Coefficient	0.15	0.26	0.36	0.42

(Total difference:)
$$\sum_1^{sample} \frac{De_{KAZR} - De_{GOES}}{De_{GOES}}$$

→ From the sensitivity study, we conclude that 0 dBZ threshold is a reasonable value and used in averaging KAZR retrievals.
 → It means the satellite retrieved D_e can be compared to the ARM KAZR retrieved D_e values averaged from cloud top down to where the reflectivity is 0 dBZ.

Can we improve the satellite night D_e retrievals?

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→ The KAZR retrievals should be the same for both day and night.
→ Both MODIS and GOES nighttime D_e retrievals are much lower than the KAZR nighttime retrievals and their daytime counterparts due to their nighttime retrieval limitations.

→ Here we propose the following two steps to improve the nighttime D_e retrievals:

Step 1: Developing some empirical relationships between daytime D_e and parameters (X, Y, Z, etc, those are also available during nighttime), and then apply this relationship(s) to retrieve nighttime D_e .

Step 2: Using the KAZR D_e retrievals as “ground-truth” to tune/modify this relationship and finally implement the modified relationship to calculate nighttime D_e values.

Conclusion II

- 1) The MODIS and GOES retrieved daytime ice cloud particle size D_e values have excellent agreement with the ARM KAZR retrievals.
- 2) The bullet rosette habits should be used for ARM retrieving the ice cloud microphysical properties of DCS.
- 3) In addition to the spatial and temporal averages, the satellites retrieved D_e can be compared to the ARM KAZR retrieved D_e values averaged from cloud top down to where the reflectivity is 0 dBZ.
- 4) Finally we propose two steps to improve the satellites nighttime D_e retrievals in the future work.



THANKS

